INJURY ASSESSMENT METHODS CHAPTER 3

3.1 Introduction

This chapter provides basic guidance on program management, quality assurance, and statistics, and introduces four general injury assessment methods (procedures), literature reviews, field studies, laboratory studies, and modeling studies. The general methods listed here are not meant to be an exhaustive list, nor are they mutually exclusive. Methods may be combined within an injury assessment study. Trustees often may find that results obtained during the early stages of an assessment suggest changes in the type or extent of ongoing assessment activities. Thus, the methods being used should be reviewed throughout the study to ensure that findings are being developed in the most efficient manner possible.

3.2 Injury Determination and Quantification

An injury assessment evaluates whether adverse effects resulted from an incident and the severity, geographic extent, and duration of those effects. Injury determination and injury quantification, respectively, are terms used to describe these two inter-related components of an injury assessment.

Determination of injury caused by direct exposure to a discharge of oil requires the trustees to demonstrate that:

- A pathway exists between the discharge and the natural resource of concern;
- The resource was exposed to the discharge; and
- Exposure has caused an adverse effect on the resource.

If an injury was not caused by direct exposure to the discharged oil, trustees should document an adverse effect and demonstrate that the effect resulted from the incident.

Injury quantification involves determining the severity, extent, and duration of the adverse effect. Trustees have the option of quantifying the adverse effect directly and/or quantifying the reduction in services provided by a natural resource caused by the incident. The natural resource or service change is defined as the difference between post-incident conditions and baseline conditions.

It is important to quantify injury in ways that allow the scale of restoration actions to be determined. For example, benthic injury may be quantified by determining the area of sediment where oil concentrations are, or have been, above a threshold concentration sufficient to cause injury. Restoration actions may then be scaled based on the area of sediment that must be restored and/or compensated.

Although the OPA regulations describe injury determination and injury quantification as separate steps, they often are performed together. Trustees should design a suite of studies that serve this dual purpose and that ultimately allow trustees to scale restoration activities to match the extent and severity of injuries. In addition, thinking about injury determination and quantification issues concurrently will result in studies that do not require additional data collection or study revision. For convenience, injury determination and injury quantification issues are discussed together throughout this chapter.

3.3 Program Management

The NRDA process can be a complex undertaking, involving a variety of technical and administrative activities, trustee staff from multiple jurisdictions, and experts from a range of technical disciplines. These various activities and personnel must be coordinated to ensure that:

- Relevant and high quality assessment information is collected;
- Critical decisions are made in a timely manner with input from all co-trustees; and
- The overall assessment is conducted in an efficient and cost-effective manner.

The level of effort necessary for program management will vary according to the complexity and significance of the incident, but regardless of the complexity, trustees should consider developing a management plan that structures both the overall injury assessment and individual components of the assessment. Planning and organizational considerations should be addressed early in the process, ideally evolving from the management structure established as part of pre-incident planning or during the preliminary assessment. Details of the individual studies should be developed by the specific investigators, but the trustees should provide overall guidance and a management framework that assigns clear responsibilities to the investigators. Common elements of a program management plan are discussed below.

3.3.1 Overall Administrative Structure

The management plan should address the overall coordination and conduct of the NRDA by establishing an organizational structure and decisionmaking process. In most cases, the trustees will develop a Memorandum of Understanding (MOU) to address basic coordination and decisionmaking. The roles of each trustee should be clearly specified. Trustee coordination is crucial to an effective NRDA because most incidents involve multiple trustees with overlapping interests. Coordination of trustee activities will avoid redundant assessment activities.

Activities that may be considered in establishing an overall structure include:

- Forming a co-trustee council;
- Selecting a lead administrative trustee (LAT);
- Determining roles of the various co-trustees and specific personnel;
- Establishing overall budgetary and cost-accounting procedures;
- Allocating assessment activities among co-trustees, including contract management;
- Scheduling; and
- Determining and facilitating participation by the RPs.

3.3.2 Lead Administrative Trustee (LAT)

The lead administrative trustee (LAT) is the agency responsible for coordinating and managing the NRDA process. This coordination is essential to the efficient and timely completion of the assessment. When an incident involves more than one trustee agency, the trustees, by consensus, should select a LAT to coordinate the assessment. The LAT does not need to be a Federal agency, nor does the LAT responsibility need to stay with one trustee over the entire assessment.

In designating a LAT, trustees may wish to consider such factors as:

- Jurisdictional or natural resource oversight (e.g., which agency has the preponderance of affected resources);
- Demonstrated technical and administrative capability and willingness to manage the NRDA process;
- Current workloads; and
- Availability of staff and supporting infrastructure.

The specific role of the LAT may be determined on a case-by-case basis. However, it is important that the role be clearly defined because of the LAT's central role. Examples of LAT duties may include:

- Coordinating the co-trustees;
- Coordinating with the RPs and response agencies;
- Scheduling regular meetings and preparing agendas;
- Overseeing completion of critical documents and distributing documents, data, and information;
- Facilitating co-trustee review and comment on draft documents;
- Maintaining the administrative record, tracking samples and evidence;
- Monitoring assessment progress and scheduling critical elements; and
- Managing recovered damages.

3.3.3 Establishment of a Technical Team

Depending upon the size and complexity of the NRDA, a technical team may be established. The management plan should include the establishment of such a team to design and implement technical aspects of the assessment. Each trustee agency should participate and, in a cooperative assessment, the RPs also may be represented. The roles of each person on the technical team should be clearly specified.

The technical team would generally have the responsibility for:

- Interpreting preassessment information;
- Establishing the scope of the injury assessment, including selection of candidate injuries for evaluation;
- Developing assessment goals, objectives, and strategies;
- Identifying specific studies and anticipated findings;
- Defining data quality management;
- Selecting contractors and experts;
- Determining appropriate assessment methods;
- Reviewing study proposals;
- Providing technical oversight of studies and interpreting study results;
- Providing site safety planning; and
- Identifying overall restoration objectives.

3.3.4 Logistical Considerations

The management plan should address logistical responsibilities by making specific assignments to trustees. Certain activities may be consolidated under one trustee's jurisdiction (e.g., the LAT may manage the administrative record) while other activities may be conducted by each trustee agency (e.g., cost accounting). Logistical considerations may include:

- Scheduling assessment activities and deliverables, including critical decision-points and key points for input from or output to other studies;
- Scheduling regular trustee and peer review meetings;
- Establishing and maintaining an information management system, including distribution of documents, maintenance of the administrative record, and evidence tracking and storage;
- Financial management;
- Facilitating public involvement; and
- Complying with statutory and regulatory requirements.

3.3.5 Litigation Requirements

The results of injury assessment studies ultimately may be used in litigation against the parties responsible for the incident. The possibility of litigation requires that trustees take additional steps in development, conduct, and management of NRDA studies. All parties involved should be aware of the relevant regulations and litigation considerations, including:

- **Scientific requirements for evidence.** Information collected during the assessment process may be used as evidence. Therefore, appropriate quality assurance and chain-of-custody procedures must be identified and followed to ensure that data and analyses are technically sound, legally defensible, and cost-effective.

- **Data and Information Management.** Data and information management are critical throughout the NRDA process. Samples, data, and other evidence must be maintained pending the final resolution of the incident and expiration of the time period allowed for any changes to, or appeals, of that resolution.

- **Cost Accounting.** Assessment costs are one element of a claim. In order to recover these costs, all persons participating in the assessment should be aware of cost documentation procedures.

3.4 General Assessment Considerations

A key element in the design and conduct of injury assessment studies (regardless of the general method selected) is a clear understanding of how the data generated during the study will be used. This section addresses three important factors related to the collection and ultimate use of assessment data:

- Use of appropriate expertise;

- Development of explicit questions that can be evaluated during the assessment; and

- Determination of the most effective techniques for analyzing and presenting the data.

3.4.1 Use Appropriate Expertise

Injury assessments are based on scientific data that often are limited and subject to conflicting interpretations. Appropriate expertise is necessary to:

- Focus and design the assessment;
- Evaluate and select assessment procedures;
- Determine the relevance and quality of available data;
- Develop hypotheses based on logic and scientific principles; and
- Interpret the significance of observed, measured or predicted impacts.

Because appropriate expertise is critical, an experienced interdisciplinary team enhances the likelihood of a successful injury assessment.

3.4.2 Develop Explicit Questions

To focus the design of each injury assessment study, trustees should clearly formulate the questions to be evaluated by the study. To do this, trustees may find it helpful to ask a number of questions.

- What are the basic facts regarding the injury?
- What additional information would contribute to the injury assessment?
- What must be measured or observed in order to obtain this additional information?
- Will it be possible to gather this information in an efficient and effective manner?
- How confident are we that the study can be carried out successfully?
- What utility will the information provide to our restoration efforts? (i.e., Will we be able to quantify the injury in a way that allows us to scale restoration actions?)

Through a careful consideration of these questions, trustees can focus each study on clear and explicit questions, thereby increasing the possibility of obtaining useful data. See chapter 2 of this guidance for a more thorough discussion of these considerations.

3.4.3 Develop Valid Study Designs[1]

Trustees should seek experienced statistical experts and consider data analysis and statistical issues at the beginning of the study design process. This section describes some of the general statistical techniques that trustees may need to consider in the design of an assessment study, but is not a complete presentation of all of the analytical and statistical techniques that could be used in an injury assessment. Trustees may wish to consult Eberhardt and Thomas (1991), Gilbert (1987), Hurlbert (1984), and Zar (1984) for additional information.

Typically, the analysis of injury assessment data requires the application of descriptive and inferential statistical methods to assess the likelihood that a change has occurred in a natural resource. These techniques can be used to describe conditions at the assessment site and at reference sites and to determine whether there are any statistically significant differences between the sites with respect to the distribution and concentration of oil and level of adverse effects that can be attributed to exposure to oil. These techniques also may be used to predict the degree of a specific response given a particular level of contamination.

The primary objective of statistical analysis is to infer the characteristics of a group based on examination of a sample from the group. The process of sampling introduces uncertainty because only partial information is acquired and observations vary from sample to sample. The variability in samples is attributable to several sources, including natural variability, chance or sampling variability, and measurement variability (also called measurement error). A primary goal of almost all statistical analyses is to identify and understand systematic effects (e.g., effects from the incident) while accounting for the influences of these sources of variability.

[1] The portions of this section that describe statistical concepts are drawn from MacDonald et al., 1992.

The logic of statistical inference is based on evaluating a particular question, formulated as a testable hypothesis or null hypothesis, on the basis of results from a sample. The hypothesis is assumed to be true and is evaluated on the basis of the statistical evidence contained in the obtained sample. It also is assumed that the sample is randomly selected so that the laws of probability may be invoked to evaluate the sample data with respect to the hypothesis. The null hypothesis is tested against an alternative hypothesis that represents an alternative explanation. A decision will be made by a test of the null hypothesis against the alternative hypothesis assuming a possible error level (significance or alpha level) of the test. Based on the value of a test statistic computed from the sample and whose distribution is determined by the null hypothesis, a measure of likelihood of the particular sample, called the significance probability (p-value), can be computed. This value is a measure of how likely the obtained sample is if the null hypothesis is true, assuming the particular assumptions of the statistical test are valid. Because of the nature of inductive inference, it is generally desirable to define the alternative hypothesis as the conclusion for which one would like to test for validity. Technically, the null hypothesis should never actually be accepted, rather it should only be concluded that there is insufficient reason to reject it.

There are two general types of statistical methods, parametric and nonparametric, that provide the primary means of testing null hypotheses. Parametric methods are employed to test hypotheses formulated about the characteristics of population parameters, such as the population mean and variance. All parametric methods are based on certain assumptions pertaining to the parent population(s). These assumptions may differ depending on the specific method.

These assumptions might include:

- Samples are collected from a population of normal distribution;
- Parent populations have the same variance;
- The size of the variance is independent of the size of the mean; and
- The samples are independent.

Sample sizes permitting, these assumptions should be tested prior to the formal application of parametric statistical tests.

Populations in environmental studies frequently provide data that do not meet the assumptions of parametric tests. One solution in such a case is to transform the data using a transformation such as the logarithmic transformation so that the data to be analyzed meet the required assumptions of the statistical method. The use of transformations, however, complicates the interpretation and presentation of the results, so this technique should be used with caution. An alternative that is becoming more widely adopted by investigators is to employ nonparametric methods in cases where parametric methods involve assumptions not apparently met by the data. Nonparametric methods involve ranking the data and do not require such stringent assumptions regarding the parent population. Thus, they are less affected by departures from assumptions than parametric methods.

Additionally, because they are based on ranks of the data, they are not seriously affected by extreme values, real or artifacts, in the data. While nonparametric methods are generally not quite as powerful in rejecting a null hypothesis as parametric methods when the assumptions of parametric methods are met, they are nearly as powerful in such circumstances, and when the conditions of parametric procedures are not met, they are clearly preferable. Statistical analysis merely provides a means of evaluating the likelihood of an hypothesis based on information generated through sampling. There are two types of significance to consider: statistical and biological. It is important for trustees to keep in mind that statistically significant results are not necessarily "meaningful" in the sense that they demonstrate the injury trustees are trying to measure. This point is made clear by the National Research Council in "Managing Troubled Waters" (NRC, 1990):

> Virtually any change can be statistically significant, depending in part on the sampling effort. Thus . . . a small sampling effort will detect only large changes, but one with an intensive sampling effort could find even extremely small changes statistically significant. Whether changes in the environment are statistically significant has no bearing on the extent to which the changes may be either meaningful or important...

The OPA regulations do not mandate that results of injury assessments meet any pre-determined level of statistical significance. In the most general sense, valid injury determination and quantification requires only the use of accepted scientific practices by competent investigators so that the results clearly indicate an adverse change in a resource or service. Statistical significance should be viewed as one tool that could help demonstrate injury.

3.5 Quality Assurance[2]

An injury assessment can include many individual studies conducted by a team of investigators using different methods and generating a variety of physical, biological and chemical data. Because these data are used to draw conclusions with respect to injury determination and quantification and may be used in litigation, all of the data must be of known, acceptable, and defensible quality and be properly documented.

A quality assurance program provides the framework for developing data with these attributes. The program should be developed and implemented at the start of the NRDA process to allow the inclusion of all of the injury determination components, including field sampling and data collection. All generated data (e.g., analytical chemistry, bioassays, field counts) are subject to the same quality assurance process.

Development of the quality assurance program is most successful if undertaken as an interactive and iterative process. The leaders of the various studies should work cooperatively with the Quality Assurance (QA) Coordinator to design and implement a realistic quality assurance plan for their work. The oversight and coordination of these various plans is the responsibility of the QA Coordinator, who ensures that the data quality needs of the NRDA are met. The size and complexity of the quality assurance program depends on the needs of the particular assessment. Trustees should keep in mind that it may be just as important to have defensible data for a spill of 5,000 gallons as it is for a spill of 500,000 gallons. The following guidance provides an outline and brief description of the components of the quality assurance program.

As described by Taylor (1987), each quality assurance program should consist of:

- **Quality Assurance:** A system of activities that provide to the producer or user of a product or a service the assurance that it meets defined standards of quality with a stated level of confidence.

- **Quality Control**: The overall system of activities that control the quality of a product or service so that it meets the needs of the users. The aim is to provide quality that is satisfactory, adequate, dependable, and economic.

- **Quality Assessment:** The overall system of activities that provide assurance that the overall quality control job is being done effectively. This involves a continuing evaluation of products produced and the performance of the production system.

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[2] This section was drafted by Carol-Ann Manen, NOAA, Damage Assessment Center, Silver Spring, MD.

In practice, a quality assurance program consists of a:

- Document describing the objectives of the injury assessment process (i.e., data quality objectives) and the QA practices to be implemented;

- Development and implementation of a set of practices that will result in data meeting the objectives (this should include compliance with Good Laboratory Practice Standards, as described in the Toxic Substances Control Act, 40 CFR Part 792, for Standard Operating Procedures (SOPs) and physical/chemical and biological test systems and specific steps or responsibilities for correcting any deviations from the desired data quality); and

- Development and implementation of a method(s) for assessing whether the program is functioning as planned.

These program elements should be documented and available for review and inclusion in the Administrative Record for the assessment.

3.5.1 Quality Assurance Practices

There are a variety of quality assurance practices currently in use; some of these practices are more useful for one type of measurement than others. Because injury assessment studies may use a variety of measurements, the quality assurance practices outlined in this guidance document represent an integration of Good Laboratory Practice Standards (GLPS), Contract Laboratory Program requirements, and experience gained from the USEPA's Puget Sound Estuary and Environmental Monitoring and Assessment (EMAP) Programs and NOAA's National Status and Trends Program.

3.5.2 Quality Assurance Project Plan

Every Principal Investigator of a data-generating study should prepare and follow a plan that defines explicitly what is to be done in each measurement situation. This plan may be referred to as a Quality Assurance Project Plan (QAPP), a QA Plan or a Sampling and Analysis Plan (SAP). Each plan should be prepared by the Principal Investigator or his(her) designee and include the data quality requirements for that study.

The plan should specify the:

- Methodology to be followed in collecting or generating the samples and data (e.g., standard operating procedures or SOPs);

- Number and types of samples and quality control materials, including procedures to be used in generating or collecting the data; and

- In-house quality assessment procedures to be used in evaluating the data.

The USEPA has developed guidance (Stanley and Verner, 1983) for what information should be included in these plans and how the information should be organized. This guidance is summarized in Exhibit 3.1. This guidance may not be applicable in total to all injury determination and quantification studies. Several of the topics included in Exhibit 3.1 are discussed below.

Project Description: If possible, the study goals should be stated as a quantitative, testable hypothesis. An example of such a statement, taken from EMAP:

> Over a decade, for each indicator of condition and resource class, on a regional scale detect, at a minimum, a linear trend of 2% (absolute) per year (i.e. a 20% change for a decade), in the percent of the resource class in degraded condition. The test for trend will have a maximum significance level of alpha = 0.2 and a minimum power of 0.7 (i.e. beta = 0.3).

This statement provides the criteria to design a sampling and analysis program within the cost and resource constraints or technology limitations that may be imposed upon the study. Also, with this statement, the uncertainty that can be accepted in the measurement data can be defined.

Project Organization: Responsibilities for field and laboratory personnel should be clearly indicated. Include phone and fax numbers.

Quality Assurance Objectives for Measurement Data: Representativeness, completeness, and comparability are difficult to quantify (Taylor 1987). They relate primarily to the study design, the selection of sampling and analytical methodologies, and the resulting data base. Precision and accuracy are quantifiable criteria that are developed for the different collection and measurement systems (and the individual components within those systems) being used in the study.

Exhibit 3-1

DESCRIPTION OF THE SUGGESTED SUBJECT AREAS OF A QUALITY ASSURANCE PROJECT PLAN

Subject Area	Description
Project Description	Each specific project description should contain a brief introduction containing relevant background information. This section also should contain a general statement of project goals.
Project Organization and Responsibility	This section should summarize the overall project organization and the responsibilities of cooperating organizations. A figure illustrating the organizational structure is usually included.
Quality Assurance Objectives for Measurement Data	This section should specify the intended use of the data, and the questions to be answered or the decisions to be made as a result of the data. This section also should spell out the data quality objectives for five aspects of the data quality representativeness, completeness, comparability, accuracy, and precision for each indicator.
Sampling Procedures and Sample Handling	This section should provide specific guidelines and protocols regarding preservation, holding times, labeling, and collection of samples for each major indicator. A description of the site selection rationale also can be included in this section.
Sample Custody, Transportation, and Storage	All samples collected should be labeled according to date of collection, sample type, sample location and sample class, and each sample should have its own unique identification.
Calibration Procedures and Frequency	This section usually describes instrument maintenance and calibration, and performance (QC) checks on instruments. Performance checks should be done on a regular, specified basis, and results should be recorded.
Experimental Design and Analytical Procedures	This section details the analytical methods to be used for each indicator. This section also discusses changes in methods (if necessary) as the project progresses.
Data Reduction, Validation, and Reporting	This section should include the criteria that will be used to validate the quality of data, the methods to be used for the treatment of outliers, equations for calculation or value of the indicator to be measured, the reporting units to be used, and a description of data verification and validation phases for the project.
Internal Quality Control Checks and Frequency	A description of internal quality control (both laboratory and field), including a description of the QC sample design and samples (i.e., splits replicates, matrix spikes), should be given in this section. If control charts are used, they should be described here.
Performance and Systems Audits and Frequency	This section describes the performance system audits (both internal and external) used to monitor the performance of the measurement systems being used for the project. If laboratories will be expected to participate in a performance evaluation program of any sort, this should be described here.
Preventive Maintenance Procedures and Schedule	Preventive maintenance to be performed on instruments on a scheduled basis, and any critical parts (those that either have to be replaced on a frequent basis, or that require extra time ordering and shipment) that should be kept on hand should be included in this section.
Specific Routine Procedures to be Used to Assess Data Quality	Specific procedures to be used for the assessment of accuracy and precision of the data for each indicator, including confidence limits, central tendency, dispersion, bias, and the five aspects of data quality should be detained in this section.
Corrective Action	The limits for data acceptability, the point at which corrective action should be initiated, and a description of the corrective action to be taken for each indicator should be included here. Corrective actions also can be a result of other QA activities; such as performance audits, systems audits, and laboratory comparison studies.
Quality Assurance Reports to Management	This section should describe the type and schedule for documents reporting on data accuracy, completeness, and precision, the results of performance or systems audits, and any significant QA or methods problems and the corrective action taken for resolution of problems.

Source: Stanley and Verner, 1983.

Accuracy is the difference between a measured value and the true or expected value and represents an estimate of systematic error or net bias. Precision is the degree of mutual agreement among individual measurements and represents an estimate of sampling, measurement, or other sources of error. Collectively, accuracy and precision can provide an estimate of the total error or uncertainty associated with an individual measured value.

Measurement quality objectives for accuracy, precision and completeness should be expressed in a quantitative manner. The Principal Investigator establishes these objectives based on the study methods and the hypothesis being tested. These objectives may not be definable for all parameters due to the nature of the measurement type. Accuracy measurements are difficult for toxicity testing or for histopathology (tissue lesions) for example, because "true" or expected values do not exist for these measurement parameters. Example measurement quality objectives are presented in Exhibit 3.2.

Objectives for accuracy and precision may be met through several mechanisms. These mechanisms are similar for field and laboratory procedures and rely upon replication, training and SOPs. Examples of field and laboratory mechanisms are given below.

Field: Counting murres nesting on rocky islands provides a good example of mechanisms to assure accuracy and precision. In this case, because the birds feed at a certain tidal height, care was taken to time the counts with the tide to count the maximum number of birds. The counts were taken while circling the islands in a ZODIAC, each ZODIAC contained 3 people, one to run the boat and two to count. The "counters" were trained in the field by the PI to recognize and identify the birds of interest. Using photographs, the islands had been divided into approximately equal zones by natural markers. The two counters counted the birds in sequential zones for 15 minutes and then traded zones. If the two sets of counts were within ±15% agreement the counters moved on to the next two zones. If the two sets did not agree, the zones were recounted. If they still did not agree, the data were marked with a qualifier. These procedures were described in SOPs that were used to guide field personnel and document how the procedure was performed.

Exhibit 3.2

EXAMPLE OF MEASUREMENT QUALITY OBJECTIVES

Sample Type	Analytical Measurement	Precision (±%)	Accuracy (±%)	Completeness (%)	Detection Limit/Unit	QC Samples and frequency (#s=no. of samples)	Acceptance Criteria	Corrective Action
Blood plasma	Testosterone Estradiol Progesterone	±15 ±15 ±15	±25 ±25 ±25	95 95 95	<20pg/100µ1 <20pg/100µ1 <20pg/100≤1	B,S,M,ES @ 3-4/assay B,S,M,ES @ 3-4/assay B,S,M,ES @ 3-4/assay	Rec. ES ≥ 60%, M(see caption), B≤ 10 pg/100µl E, Rec. S ± 25%	B, Es, S, M Recalibrate and/or reanalyze
Blood Plasma	Protein bound phosphorus Gonadotropin	±15 ±15	n/a ±25	95 95	<10pg/100µl <50pg/100µl	B,D @ 3-4/assay B,D,S @ 3-4 assay	RPD of D ≤ 20%; B record data S ± 20%; RFD of D ≤ 20%; B ≤ 50 pg/100µl	Recalibrate /re-analyze; B; correction factor B,D,S; Recalibrate and/or reanalyze
Liver	Estraduik receptor assay E-2 Competition assay	n/a n/a	n/a n/a	95 95	n/a n/a	D,SD D,SD w competitor	SD; realistic Kd; RFD of D ≤20% SD competitor, shows displacement, RPD of D ≤ 29%	D, SD; Recalibrate and/or reanalyze –
Pituitary	Gonadotropin release	±15	±25	95	<50 pg/100µl	B,C,D,S	S ± 25%; RPD of D ≤ 20%; B ≤ 50 pg/100µl, C < Stimulated samples	B, C ,D, S Recalibrate and/or reanalyze
Gonad	Estradiol release Testosterone release	±15 ±15	±25 ±25	95 95	<1 pg/1 mg <1pg/1 mgl	B,C,M,S B,C,M,S	S ± 25%, RPD of D ≤ 20%; B < 1 pg/1 mg M (see caption)	B, C, M, S Recalibrate and/or reanalyze
Egg suspension	Fertilization success Germinal vesicle breakdown Embryological success Egg diameter	±5 ±5 ±5 ±5	±10 ±20 ±15 ±5	95 95 95 95	n/a –	D,V @ 5% for all samples D,V @ 5% for all samples D,V @ 5% for all samples D,V @ 5% for all samples	D, V ≤ DQO –	and/or reanalyze
Larval	% abnormal larvae	±5	±10	95	n/a	D,V @ 5% for all samples	D,V ≤ DQO	D, V Recalibrate and/or reanalyze
Various tissues	Tissue lesions	±25	n/a	95	n/a	D,V @ 5-20% for all samples	concurrence of analysts	D, V Reanalyze
Water (T= tank) (I = influent)	Temperature Ph Dissolve oxygen Ammonia (NH-3) Conductivity	±0.1°C ±0.1 units ±0.1 mg/1 ±°0.1 mg/1 ±10µMho	±0.1°C ±0.1 units ±0.1 mg/1 ±°0.1 mg/1 ±10µMho	95 95 95 95 95	n/a –	R @ daily R @ daily (I), R @weekly(T) R @ daily (I), R @weekly(T) R @ daily (I), R @weekly(T) R @ daily (I), R @weekly(T)	R = certified value –	instrument and reanalyze

B=blank, C=unstimulated control, D=duplicate, M=multiple dilutions, R=calibrate by SOP with standard reagents, S=spike, ES=extraction spike, V=verification by alternate method (or individual), E=extract, RPD=relative percent difference, SD=serial dilution. For M, two dilutions are measured, the result from the lower dilution extrapolated to higher dilution, and RPD of extrapolated value and measured value ≤ 20%

Laboratory: For analytical chemistry, one of the most useful measurements of accuracy and precision is the repeated analysis of certified reference materials (CRMs) and Standard Reference Materials (SRMs), which are samples in which chemical concentrations have been determined accurately using a variety of technically valid procedures. These samples are issued by a certifying body (e.g. agencies such as the National Research Council of Canada (NRCC), USEPA, U.S. Geological Survey, National Institute of Standards and Technology (NIST)). A useful catalogue of marine science reference materials has been compiled by UNESCO (1993).

Completeness refers to the number of data points that meet the data quality objectives, i.e. those that are acceptable with no data qualifier. In the above field example, if one or more of the counts did not meet the precision objective, they were marked with a qualifier. Qualification does not mean that these data cannot be used, but that the qualified data should be used with caution as they may or may not be adequate for the project needs.

Sampling Procedures and Sample Handling: SOPs describing sample collection or data generation procedures, including the labeling, handling, and preservation of the samples, should be written in detailed, clear and simple language. Personnel must be knowledgeable and experienced in the sampling techniques described and must adhere to the SOPs.

Samples should be labeled at the earliest possible opportunity to minimize the chance of confusing one sample with another. The minimum information to be included on the tag or label identifying the sample are the sample identification number, the location of the collection site, the date of collection, the name/signature of the collector, and sample description (who, what, where, and when). This information and any other pertinent data such as the common and scientific names of the organism collected, the tissue collected, and any remarks also are recorded in the logbook.

All information pertinent to sample generation and collection techniques, including descriptive notes on each situation, must be recorded in indelible marker in a bound logbook. The information must be accurate, objective, up-to-date, and legible. It should be detailed enough to allow anyone reading the entries to reconstruct the sampling situation. Additional information may be provided by data sheets, sample tags, photographs, or videos.

Sample Custody, Transportation and Storage: Samples and log books must be kept in such a manner that they cannot be altered either deliberately or accidentally. Any indication that a sample has been subjected to tampering or physical alteration could disqualify it as evidence. The sampler is personally responsible for the care and custody of the samples collected until they are transferred under chain of custody procedures. A sample is considered in *custody* if: it is in your actual physical possession or view, it is retained in a secured place (under lock) with restricted access; or it is placed in a container and secured with an official seal(s) such that the sample cannot be reached without breaking the seal(s).

When samples are transferred from one individual to another, even within the same facility, they must be accompanied by a chain of custody record. Exhibit 3.3 provides an example of a chain of custody record. The individuals relinquishing and receiving the samples must sign and date the chain of custody record in indelible ink at the time that the samples are transferred. The completed original form accompanies the samples. The person who relinquished the samples should keep a copy of the form.

Because the NRDA process may be lengthy, trustees should archive all samples, raw data, and data documentation under chain of custody and in a manner to preserve their integrity until the case has been resolved.

Calibration Procedures and Frequency: These procedures apply to instruments as diverse as balance scales, thermometers, pH meters, current meters, and gas chromatographs. In all cases, the procedures must be performed and the results recorded in logbooks. At a minimum, all similar instruments should be calibrated against the same standard. Calibration to standards developed by the NIST provides consistency with a national dataset and strengthens the credibility of the developed data.

The remaining topics on Exhibit 3.1 should be addressed in SOPs covering all field and laboratory procedures, instruments, and analyses.

Exhibit 3.3
CHAIN OF CUSTODY FORM

NOAA DAMAGE ASSESSMENT CENTER
CHAIN OF CUSTODY FORM

1305 East-West Hgwy, Rm 10229, Silver Spring, MD 20910
For more information contact Douglas Helton
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Project _____
Sampler_____

Sample I.D.	Date Collected	Location	Sample Type (Tissue, oil, water, Include species name and tissue type)	Comments

Collected by: (signature)	**Received by: (signature)**	**Condition:**	**Date/Time**
Relinquished by: (signature)	**Received by: (signature)**	**Condition:**	**Date/Time**
Relinquished by: (signature	**Received by: (signature)**	**Condition:**	**Date/Time**

3.5.3 Quality Assessment

All data generating activities should be audited by independent external personnel. These audits should include:

- System audits conducted to qualitatively evaluate operational details; and

- Performance audits conducted to evaluate data quality, adequacy of documentation, and technical performance characteristics.

The audits should use comparisons to the quality assurance documentation developed for that activity, that is, these audits should confirm the quality of the data. If there are discrepancies between the documentation and actual operations, the quality assurance program manager should determine if the discrepancy will significantly affect the ability of the trustees to successfully conduct the injury assessment. This may require reanalysis of existing samples or collection of new samples. For this reason, quality assessment should be conducted in a timely fashion so that any necessary changes can be made before the project concludes.

3.6 Assessment Methods

There are a number of injury assessment methods available to trustees, including literature reviews, field studies, laboratory studies, and modeling studies:

Literature reviews are an important first step in planning any injury assessment study and is an important method, either alone or in combination with field, laboratory, and/or modeling studies. The systematic compilation of data from previously completed studies may suggest that injury to one or more natural resources has occurred. This approach also may provide information about gaps in knowledge that may be filled by proposed assessment studies.

Field studies are the most direct means to evaluate injury. In general, these studies require the careful collection and analysis of data to determine spatial and temporal relationships.

Laboratory studies offer a less direct, but often equally effective, means to determine that a natural resource may be injured due to exposure conditions similar to those in the field. The results of laboratory studies may provide additional evidence to support observations made in the field, although laboratory studies sometimes stand alone in determining that an adverse effect is possible.

Modeling provides a means to simulate the interactions between oil and the environment (e.g., flow and dispersion models) and predict the environmental consequences of an incident. Models may be used as a complete assessment tool for small incidents or to address specific components of an injury assessment for a larger incident. Models may also be useful for screening, to focus an assessment on the most probable injuries, or to integrate other assessment techniques.

These methods may be used alone or in combination. For example, during the design of the injury assessment, trustees should include studies that will demonstrate pathway and exposure. These studies may include:

- Field data (e.g., aerial photos, water and sediment samples) along the pathway the oil is thought to have followed;
- Published literature on the uptake of oil by the natural resource of interest;
- Laboratory studies that demonstrate bioavailability and uptake; and
- Modeling studies that simulate both physical movement from source and biological uptake.

These general methods are described in more detail in the following sections.

3.6.1 Review of Existing Literature

Many of the injuries resulting from oil are well documented. By collecting and reviewing the literature from case histories and field and laboratory studies, trustees can focus their efforts both on the natural resources most likely affected and the types of data needed to evaluate and quantify the injuries to those natural resources.

To be most useful, the literature studies should match the incident in the following parameters:

- *Oil type and amount*: Is the oil type in the incident similar to that in the literature study?

- *Resources of interest*: Are the natural resources affected by the incident the same or similar to those studied in the literature?

- *Fate of the oil*: Is the behavior of oil during the incident similar to the behavior of the oil in the literature study? Are exposure pathways to affected natural resources the same?

- *Acute or chronic discharge*: Is the duration of exposure in the literature study similar to that observed in the incident?

Case histories are important sources of information on oil behavior and fate, and can be used to develop conceptual models for pathways of exposure. Although each incident is a unique combination of events, there are consistent patterns in oil behavior and effects. However, much of the case history literature considers medium to large marine oil discharges, with little published information on freshwater or terrestrial discharges.[3]

Case studies may also be important sources of data on the degree and duration of injuries. For example, the recovery rate for an oiled marsh could be established from studies conducted at previous incidents similar in type and degree of oil contamination, vegetation type, and physical setting to the present discharge (e.g., Alexander and Webb, 1983, 1985, 1987; Bender et al., 1980; Delaune et al., 1984; Holt et al., 1978).

Data from previously conducted laboratory and field studies may be used to predict the type and extent of injuries. For example, projections of the number of birds in a nesting colony that will not produce fledglings after being exposed to oil can be estimated from published studies (Eppley and Rubega, 1990; Fry et al., 1986; Peakall et al., 1982; Trivelpiece et al., 1984).

[3] Refer to the American Petroleum Institute, which published two reports on fresh water oil spills.

A range of options is available for literature review. At a minimum, trustees can conduct a preliminary review of major data sources and relevant published literature. The next level of effort would be more appropriate in situations where there is a considerable amount of data of sufficient quality that could be validly applied to a specific injury study. In some cases, this approach might take the place of original field or laboratory studies. In others, it would allow trustees to identify important areas to focus new assessment efforts. For example, if a discharge of crude oil has impacted a shellfish bed, the trustees may search the published literature to determine the range of possible adverse biological effects to this natural resource that could result from the oil. If the trustees determine that there are numerous studies that document the effects of this type of oil on the specific shellfish in question, they then may determine that additional injury studies are not needed and focus their attention on pathway determination and injury quantification.

Alternatively, if the trustees determine that there are a number of studies that demonstrate effects of crude oil on other types of shellfish, then the trustees may wish to expand their search to determine whether these species are good indicators of likely effects for the species of shellfish in question. If not, the trustees can consider conducting field studies and/or laboratory-based exposure studies to determine the adverse effects.

3.6.2 Field Studies

Field studies may provide the most relevant and direct evidence for injury determination and quantification. Data developed by direct observation, photographs, videos, and samples of biota, sediments, and water may be used to evaluate:

- Whether there is a pathway from the point of discharge to the natural resource of concern;

- Whether the natural resource was exposed and injury has occurred (injury determination); and

- The degree and extent of the injury (injury quantification).

However, field studies may be hampered by the lack of true reference sites and a clear assessment of within treatment variation may be difficult. This problem may confound conclusions about the cause of any observed differences between stations. For example, differences between stations could be due to difference in habitat (e.g., fresh water input, wave energy, etc.), rather than exposure to oil. This is one reason that the most convincing evaluations of the effect of discharged oil on natural resources include three types of information:

- Assessment of effects in the field;
- Chemical data; and
- Toxicity data.

The ultimate selection of field assessment strategies and sampling designs will depend on the unique nature of the discharge, and goals of the trustees. In all cases, the design and implementation of the field studies requires a thoughtful consideration of the sampling design and strategy.

Spatial and Temporal Design of Field Studies[4]

Field study designs include:

- Pre- and post-incident comparisons within the impact area;
- Post-incident comparisons between impact and reference areas;[5]
- Pre- and post-incident comparisons between impact and reference areas; and
- Gradient comparisons.

A brief description of each type appears below. Trustees may not have a choice among these comparison types, as some depend on the availability of data collected before the incident.

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[4] The text in this section and the next has been taken, with slight modification, from text originally drafted by Lyman McDonald, WEST, Inc., Cheyenne, WY.

[5] The terms *reference*, *control*, and *baseline* are often used interchangeably to identify sample locations that have not been subjected to the effects of the particular incident being studies.

Pre- and post-incident comparisons within the impact area allow determination and quantification of injury when characteristics of the impact area or affected population(s) have been measured prior to the incident and can be measured again (ideally using comparable protocols and procedures) following the incident. This type of comparison may be particularly useful in areas that are more susceptible to accidental discharges or are subject to repeated threats of discharge, since ongoing monitoring efforts may have been established with the express purpose of providing comprehensive baseline data. However, ecological systems are not static and environmental conditions will vary over time, so any change observed in the impact area during the pre- and post-incident periods could conceivably be unrelated to the incident. During an extended study period, significant natural changes might be expected.

Post-incident comparisons between impact and reference areas are more common because pre-incident data is usually lacking in the reference areas. Simply observing a difference between impact and reference areas following a discharge does not necessarily mean that the incident was the cause of the difference. Similarly, the absence of any differences may not be an indication that there were no impacts from the incident.

A common problem for the design of field studies is the difficulty in finding suitable reference areas. Exact replicas of impact areas do not exist. Trustees should find reference areas that are as similar as possible to the impact area while recognizing the inherent differences between them. One approach is the stratification or classification of the impact area according to a set of specific, objective criteria (e.g., climate, geology, substrate, hydrology/hydrodynamics, biota) followed by the identification of potential reference areas that are closely matched on the basis of these characteristics. The spatial and temporal variability of these environmental parameters also are important considerations when comparing impact areas with potential reference areas. Trustees should select reference areas based on the use of a predetermined set of criteria. Trustees should consider the use of two or more reference areas.

Pre- and post-incident comparisons between impact and reference areas (commonly referred to as before-after/control-impact, or BACI, comparisons) are intended to address the two potential difficulties associated with the comparison types described above through a combined comparison. Natural variability in an impact area can be assessed through the analysis and comparison to data from reference areas. At the same time, variability over time can be accounted for through the use of pre- and post-incident data.

Gradient comparisons between impact and non-impact areas or within an impact area are useful for the determination and quantification of injury in a relatively small impact area within a homogeneous environment. The gradient comparison is based on the assumption of a dose-response relationship in which varying levels of biological response are correlated to decreasing contaminant levels extending out from the point of discharge. If a gradient of biological response is identified along the contamination gradient, the magnitude of differences can be translated into a minimum estimate of the amount of injury. Careful consideration should be given to natural gradients that could be confounded with effects from the incident. Gradient comparisons are analogous to laboratory toxicity tests conducted along gradients of toxicant concentrations.

Field Sampling Strategies

Census is the most direct type of sampling. Examples where it may be effectively used include counting all dead birds killed by a discharge of oil. Difficulties with this method include the potential for undercounting. Bodies may drift off, sink, be buried or scavenged, and adjustments may be necessary to account for this undercounting. Costs associated with conducting census studies over large areas also limit the usefulness of this approach for many natural resources. For example, even in a small study area it may be impossible to conduct a census of all dead bivalves. Sub-sampling within impact and/or reference areas is one way to overcome the limitations of total census studies.

Sub-sampling will allow the trustees to cost-effectively sample a large area. The design of sub-sampling plans will, in large part, determine the trustees' ability to make comparisons between impact and reference areas. In general, there are four types of sub-sampling plans - haphazard sampling, judgment sampling, probability sampling, and search sampling (Gilbert, 1987).

- ***Haphazard sampling*** is collection based on convenience, which may introduce bias into the results and reduce the chances of generating statistically meaningful conclusions.

- ***Judgment sampling*** is based on the investigator's knowledge of the study area and ability to subjectively select appropriate sample locations. While this method reduces the potential for bias compared to haphazard sampling, it does not eliminate it entirely.

- ***Probability sampling*** provides a means for making statistical inferences through the random selection of sites within impact and reference areas. There are several types of probability sampling:

  In ***true random sampling***, each sample site is selected independently of all other sites. This method provides a representative set of samples within impact and reference areas, but in practice random locations tend to be less evenly distributed than would be expected.

  Stratified random sampling guarantees that sampling will occur over previously defined sub-areas, or strata. Strata can be defined on the basis of factors such as habitat type, depth (of soil, sediment, water, etc.), oil concentration, and physiography. Sub-areas can be stratified further depending on the needs of the assessment. Within each stratum, sample sites can be selected randomly or with one of the other techniques described below.

  Random start systematic sampling begins with a random starting point rule and distributes the locations of sample sites uniformly (using lines or grids) over the impact or reference areas. Systematic sampling has been proposed as a suitable alternative in cases where stratified sampling may not be appropriate (e.g. long duration, potential misclassification of sample sites or changes in site classification).

  Sequential random sampling may be useful if the cost of laboratory analyses is a primary consideration during the assessment and only as many samples as are necessary are submitted for analysis. The ability to use rapid-turnaround field analysis instruments may warrant sequential sampling, since the results from the analyses of one set of samples can help determine the need for additional samples.

- ***Search sampling*** involves the identification of local "hot spots" where the measure for injury responses is relatively high. This can be accomplished through systematic sampling on a grid of points arranged in a certain pattern. If no measured response values exceed a pre-determined standard, trustees could conclude that hot spots do not exist. The detection of hot spots would lead to a decision regarding the need for additional sampling to quantify injury more accurately.

3.6.3 Laboratory Studies

Laboratory studies may serve multiple purposes including injury, pathway, and exposure determination. Properly designed and implemented laboratory studies may provide substantiation or confirmation of conclusions suggested by field studies. Conversely, the results of laboratory studies also may suggest the types of field studies that will be necessary to evaluate injury. In general, short-term studies that measure acute mortality are easier to design and conduct than long-term, multi-generational studies that attempt to measure on-going sublethal effects.

Toxicity Tests

Toxicity tests determine whether the discharged oil can have a measurable effect on the exposed biota. When combined with field surveys documenting a pathway and adverse effects in the field, toxicity test data may establish the causal link between the discharge and injury. The objectives of toxicity tests are to correlate an adverse effect with exposure to the discharged oil and determine the concentrations at which the effect occurs. An adverse effect may be determined directly by exposing the organisms to the oil discharged or inferred by measuring the concentration of oil either in the organism or its environment and comparing this value to literature values associated with adverse effects. While mortality is the most common effect measured in toxicity tests, these tests are also commonly used to measure developmental abnormalities, behavioral changes, changes in reproductive success, and alteration of growth.

Bioavailability Studies

Bioavailability studies may be either the measurement of tissue residues in indigenous organisms or tests of surrogates exposed to contaminated environmental media (water or sediment) for a specific length of time. Bioavailability studies are complicated by the rapid metabolism of petroleum hydrocarbons by almost all organisms except bivalve mollusks. In practice this means that analyzing any vertebrate animal and the majority of invertebrate animals for the presence of petroleum hydrocarbons will yield non-detectable results. For this reason, bivalve mollusks, such as oysters and mussels, are often transplanted to the discharge site to determine the availability of oil to biota. An alternative is the use of surrogate organisms, such as lipid bags, which provide passive bioavailability data.

A second alternative is the analysis of bile for the metabolites of the petroleum hydrocarbons. Many vertebrates excrete petroleum hydrocarbon metabolites in their bile. This tissue can be quickly and easily screened for the presence of these compounds in a semi-quantitative manner (Krahn et al., 1988).

Biomarkers

Biomarkers are ". . . biochemical, physiological, or histological indicators of either exposure to, or effects of, xenobiotic chemicals at the suborganismal or organismal level" (Hugget et al., 1992). Exposure indicators establish that organisms were subjected to a potentially deleterious stressor and quantify the extent of that exposure. However, exposure indicators cannot be used to detect adverse effects. In contrast, response indicators demonstrate that adverse effects are occurring, although often it is difficult to link the cause of the effect to exposure to the discharged oil. Thus, in most instances both response and exposure indicators are needed to establish that effects are occurring and to link the causes of those effects to oil exposure.

Exposure and response indicators include, but are not limited to, the appearance of metabolites in bile, the production of detoxification enzymes, genetic disorders, histopathological disorders, pathological deformities, and impaired reproductive abilities.

3.6.4 Modeling Studies[6]

Scientists frequently use models to describe or quantify physical, chemical, and biological processes and systems. In general, models consist of mathematical equations that require the user to specify the value of input variables, boundary conditions, and other parameters (e.g., rate constraints) in order to apply the model to a particular situation. Scientists can then use the model to study how a specific process or system will respond to changes in input variables and other parameters and may predict how a process or system might change in the future.

Models are abstractions of real processes and systems and are useful because complex phenomena can be studied in a structured, controlled way. By necessity, models are simplifications of real processes. It is not possible to build all of the complex interactions that occur in a real system into a system of mathematical equations. It is important, however, that the model successfully simulate the important processes occurring in any system. Model validation is a technique used to make this determination. For injuries to natural resources resulting from a discharge of oil, models must be able to simulate the processes occurring without the presence of oil, as well as simulate the movement of oil throughout the system after it is discharged. This requires an understanding of how the oil interacts physically, chemically, and biologically with the environment.

[6] The text in this section was drafted by Deborah P. French, Applied Science Associates, Narragansett, RI.

The sensitivity of model results to changes in inputs or parameters can be studied and uncertainty quantified. If a model's output is extremely sensitive to small changes in a given input or parameter, the trustees can consider allocating resources to studies that will increase confidence in the value of that particular input or parameter to be used in subsequent model analyses.

Strategies for the Use of Models

Models may be used as a predictive or screening tool. In the Preassessment Phase, for example, the trustees could use a model to approximate potential injuries. Model results would be used to develop an injury assessment plan, such that the focus of further studies would be on those resources expected to be injured.

Trustees may also use models as stand alone assessment procedures. For example, the type A models developed by the U.S. Department of the Interior (USDOI), including the Natural Resources Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME) and for Great Lakes Environments (NRDAM/GLE), are valid assessment tools for small spills (French et al., 1994 a, b,c; Reed et al., 1994). Trustees may combine limited studies with these models. For example, field observations and surveys may be used to improve input parameters or to help validate the model predictions. More comprehensive studies may be conducted to address injuries not included in the model, or to replace sections of the model with site-specific injury information.

Alternatively, models may be used in support of specific injury determination and quantification elements. For example, fate and exposure models may be used in support of pathway and exposure determination studies.

Several types of models may be useful for injury assessment studies. Physical models, such as oil trajectory models, sediment transport models, hydrodynamic flow models, and, more generally, physical and chemical fate and transport models may be used to demonstrate physical pathways. Results from physical and chemical models may be used in biological effects models to estimate the effects of oil discharges on biological resources. Concurrent use of laboratory and/or *in situ* toxicity and bioaccumulation studies may provide calibration or validation data. Population models may be used to estimate future changes in populations as a result of acute toxicity and/or reproductive impairment effects caused by oil discharges. A biochemical, or toxicokinetic, model may also be useful in determining the mechanisms by which contaminants cause natural resource injuries.

Oil Spill Modeling for NRDA

There is a large body of literature available on oil spill modeling, including reviews by Stolzenbach et al (1977), Huang and Monastero (1982), Murray (1982), Huang (1983), Spaulding (1988), Reed (1992), French (1992), ASCE (1994), and Spaulding (1995). The reader is referred to these reviews for details. Only a brief summary is presented below.

Fates Models

Fates models may be used to predict the behavior, transport, and weathering of oil in the NRDA context. This information may be used to predict the temporal and geographic extent of exposure and the potential for injury to natural resources. Models vary in complexity and design. Fates models are available to predict weathering the process of evaporation, dispersion, dissolution, emulsification, photolysis, biodegradation and sinking/sedimentation, and transportation (spreading, drifting, entrainment, and stranding).

Two primary methodologies for representing the physical distribution of oil have evolved. The first describes surface oil as one or more uniform circular (or elliptical or rectangular) spillets, with radius, thickness, and other variables computed dynamically. This allows easy calculation of surface area and facilitates the inclusion of fates processes that depend on surface area and thickness. A second approach describes the oil as a large number of individual particles. On the surface, the particles may take on the characteristics of spillets. In the water column, a particle takes on the characteristics of a droplet. The buoyant behavior of different sized droplets, combined with vertical shear in the velocity profile, allows a realistic representation of slick evolution. The approach can also follow hydrocarbons entrained or dissolved in the water column.

Biological Effects Models

Fate models provide a mass balance and chemical characterization of oil in two phases, as surface slicks and as subsurface concentrations in water and sediments. The output of a fate model is a three-dimensional description of oil components as a function of time. This information may be used as input to a biological effects model. Typically, surface slicks are assumed to be lethal to wildlife (mammals, birds). Smothering of intertidal plants, invertebrates, and vertebrate eggs and larvae is potentially lethal depending on oil type and thickness. Subtidal biota have not been shown to be affected by slicks on the surface. Water and sediment concentrations of petroleum hydrocarbons may be lethal to fish, invertebrates, and plants, but have not been shown to cause wildlife mortality directly. Indirect and sublethal effects may also be induced by water and sediment concentrations of petroleum components. These may impact all biota.

Biological effects models consider one or more of these exposure pathways for mortality and sublethal effects. Some models also include population-level responses to these effects. The literature on oil effects modeling is much smaller than that for fates modeling. Only one review (French 1992) appears available. Below are summaries of some of the methods used in oil spill biological effects models.

The greatest uncertainty in modeling mortality appears to be in the estimation of the probability of being oiled and dying from it. Estimation of the number of animals oiled has been performed at three levels of sophistication:

- The animals are assumed stationary and the area swept by the slick determines the number oiled (Trudel, 1984; Trudel and Ross, 1987; Trudel et al., 1987, 1989; French and French, 1989; French et al., 1994a; Reed et al., 1994);

- The average slick area over a time step may be calculated and animal movements over that time calculated. Animals moving through the slick area are oiled (Ford, 1985; Ford et al., 1987; Samuels and Lanfear, 1982; Samuels and Ladino, 1984; Brody, 1988); and

- Both oil slicks and animals are treated as Lagrangian particles, with intersections of oil and animals calculated dynamically (Reed et al., 1987a,b; French and Reed, 1989; French et al., 1989; Jayko et al., 1990).

The third method using Lagrangian particles is most realistic in that active, directed, and individualized behaviors, as well as exposure histories, may be simulated. However, hundreds or thousands of particles may be needed to achieve necessary resolution. Detailed migrational simulations are only possible if behavior is known. For some populations, the assumption of random movements may be more appropriate. Also, for general applications and where computer run time is a consideration, the simpler approaches may be appropriate.

Population modeling of wildlife impacts once mortality is estimated is well developed in the oil spill modeling literature and the general ecological literature. The primary limitation on population modeling is the availability of data for estimating population parameters.

Estimation of exposure and mortality of fish and invertebrates has been modeled at four levels of sophistication:

- Laevastu and others at the National Marine Fisheries Service (NMFS-NWAFC) developed a subsurface oil fishery mortality model. (Laevastu and Fukuhara, 1984; Laevastu et al., 1985; Fukuhara and Natural Resources Consultants, 1985). This model provides three-dimensional quantification of the water soluble fraction over time. Fish and eggs migrating or advected through the oil are assumed killed in those areas where the water soluble concentration exceeds a threshold value. A full fisheries population and catch model is then used to evaluate impacts. (Fukahara and Natural Resources Consultants (1985.)

- Reed, Spaulding and others at Applied Science Associates developed a fisheries impact model based on oil-induced egg and larval mortality. (Reed and Spaulding, 1979, 1984; Reed 1980; Reed et al., 1985; Spaulding et al., 1983, 1985.) This model uses Lagrangian particles to trace the movements of eggs and larvae as they are dispersed by currents and random mixing. Those particles exposed to oil concentrations exceeding a threshold are assumed killed. The model includes a fisheries population and catch model.

- The biological effects model developed for the CERCLA Type A NRDAM/CME and NRDAM/GLE (French 1991; French et al., 1994 a,b,c; Reed et al., 1994) includes a dynamic assessment of the exposure history of individual organisms to oil in three-dimensional space and time. The type A models use Lagrangian particles to trace the time history and concentration of exposure of individuals. This exposure history is functionally related to mortality. Standard fisheries models are used to estimate population effects and lost catch.

- French et al., (1989) developed a single-species model similar to the type A models described above. The model simulates detailed spatial distributions of adults as well as Lagrangian-particle-traced eggs and larvae. Impacts to particular beds, as well as the whole population, are assessed. The population model includes age-specific density-independent and density-dependent mortality.

3.7 References

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